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Studies on Optimizing Beam Optics and Orbit Correction for BEPC Ⅱ-Linac

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Abstract To meet the upgrading goals of the BEPC Ⅱ-linac, the beam modeling and studies on optimizing the optics for high current electron and positron beams are carried out. An optics-tuning scheme is defined. The effects of initial beam axis deviation and machine alignment errors on normalized beam emittance growth and on beam orbit offset are systematically studied, and the orbit correction with "1-to-1" correction scheme is modeled.

Key words electron linac, beam optics, orbit correction

1 Introduction

The main upgrading goals of the injector linac for Beijing Electron Positron Collider (BEPC Ⅱ-Linac) are the increase of the beam energy from 1.3 GeV to 1.89 GeV, the upgrade of the positron beam current from ~4 mA to 40 mA (thus the positron injection rate to the storage ring≥50 mA/s) and the improvement of the operation reliability and stability. To meet these goals, we have to find the new beam optics, to establish the optics tuning and orbit correction systems to partially cure the beam blow-up due to chromatic/dispersive and wake field effects caused by the high current and machine errors, and hence to ensure the required beam transmission, the emittance and energy spread. The concrete requirements of these studies are as follows: 1) optimize the e^+ beam optics by adding the quads with large aperture ("ridded" on the accelerating tubes) to the existing triplet quads, to strongly focus the high current e^+ beam with large emittance and hence to avoid the beam loss; 2) minimize the primary e^- beam spot size on the e^+ production target for having a high positron yield by optimizing the primary e^- beam optics; 3) establish an orbit correction system and partially cure the normalized emittance growth and beam instability caused by the initial high current beam offset and machine misalignment.

2 Studies on optimizing the beam optics and its correction

2.1 Features of the existing lattics

Electron beam leaves the bunching section with solenoid focusing system, then enters into the main linac quadrupole focusing system that consists of 15 triplet quads. These quadrupoles are divided into two groups according to their parameters[1], and are non-uniformly distributed along the linac, since one needs a long drift section for the installation of e^+ production target, and then followed by four triplets with a short triplet spacing to offer a strong focusing for the first 200 MeV e^+ beam in the original BEPC-Linac design. Therefore, the available transverse focusing lattice in the linac is not a serious periodic structure. Another factor acting on the lattice is the strong energy-dependence on quad's focusing strength k in the electron linac, $k=\frac{1}{B\rho}\frac{\partial B}{\partial r}$, with $B\rho(\mathrm{T\cdot m})=333.564p$

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(GeV/c), since the beam energy increases rapidly along the linac. During the machine operation, any change of each klystron output and/or the change of the stand-by klystron positions must cause the changes of the downstream beam optics. Therefore, to keep the optimum beam optics in electron linac, we have to well control the power and phase instability for each klystron, and to quickly adjust the downstream quad's strength when above changes happen.

Electron beam optics

Based on the existing lattice features, however, our studies with TRANSPORT-code[2] have shown that one can optimize the optics by fitting the beam envelope at each triplet, described as follows:

a) Each triplet has two independent variable magnetic gradients and can be used to fit two beam envelopes (σ_x, σ_y) at the closest downstream triplet, since the maximum envelopes usually appear at the triplets. One can set $\sigma_x(z) = \sigma_y(z)$ to form circle cross sections of the beam along the linac;

b) Due to the decrease of non-normalized emittance with energy increasing, the fitted σ_x and σ_y can decrease too along the linac (say from 4.0 mm to 1.5 mm). Figs. 1 and 2 show the modeling results of electron beam optics by using TRANSPORT-code for the triplets' polarity arrangements of DFD-DFD and DFD-FDF, respectively. The distributions of the magnetic gradients of the triplets along the linac are almost the same for these two lattices[3].

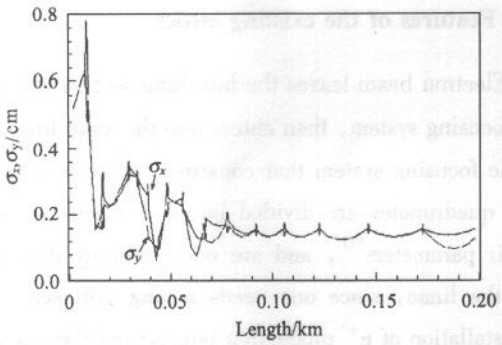

Fig.1. σ_x and σ_y along the linac (DFD-DFD).

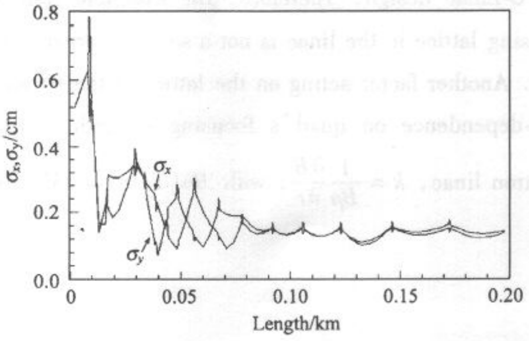

Fig.2. σ_x and σ_y along the linac (DFD-FDF).

2.3 Optics of primary electron beam for the positron production

In the BEPC Ⅱ-Linac, a 240 MeV, ~6A primary electron beam is bombarded on the positron production target. There are two triplets between the pre-injector exit (end of the solenoid focusing) and the target. The beam modeling results show that one can confine the beam spot sizes (σ_x and σ_y) and the beam waists ($\alpha_x = \alpha_y = 0$) at the target by fitting the 4 valuable gradients of these two triplets.

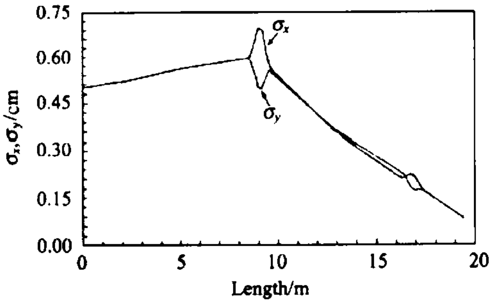

Fig.3. Primary electron beam's σ_x and σ_y along the section (DFD-DFD).

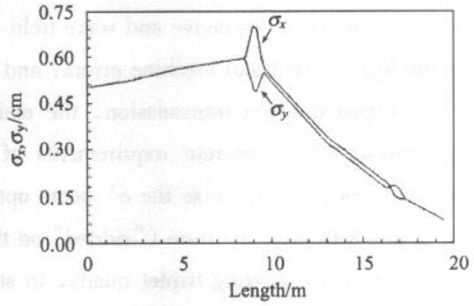

Fig.4. Primary electron beam's σ_x and σ_y along the section (DFD-FDF).

Figs.3 and 4 show the envelope distributions of the primary electron beam in this region for the triplet lattices of DFD-DFD and DFD-FDF, respectively, and their distributions of the magnetic gradients of the triplets are almost the same too[3]. Given the primary electron beam energy, beam current and the positron production target structure, the positron yield is almost inversely proportional to the spot size of the electron beam at the target. The studies on the primary electron beam spot size issue are carried out on the existing BEPC-Linac (140 MeV at target) and the minimization of the spot size for the BEPC Ⅱ case (240 MeV at target) is modeled and studied too[4].

2.4 Positron beam optics

The positron beam energy at the exit of the uniform solenoid (0.5 T, 7.0 m long) is about 80 MeV—100 MeV. If one only uses the available triplets to focus the beam transversely then the positron beam envelopes are larger than tube bore radius for the first 500 MeV[3], due to its very large emittance and transverse momentum (given by EGS4 + PAMELA codes) at the solenoid exit. Thus, an additional series of big bore quads "ridded" on the accelerating structures in this energy region is certainly needed to decrease the beam envelopes. A possible arrangement of the big quads on a 3-meter long accelerating tube is shown in Fig.5. There are an input-and an output-couplers in both ends of a tube, two support-plates are at about 1 m far from each end, and two cooling water pipe-connectors (in-let and out-let) in the middle, hence four quads (24.7 cm long each) can be installed on each tube.

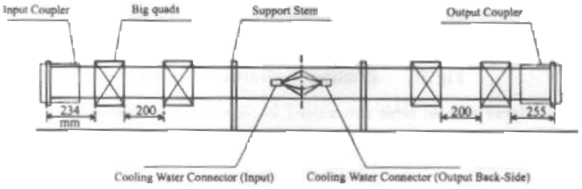

Fig.5.　Side-view of accelerating tube and locations for big bore quads.

There are totally existing 24 pieces of such quads available, but should be optimum rearranged. On each of the first 5 accelerating tubes (A8 – A12) we will install 4 quads, while the rest 4 quads will be installed on the tubes of A13 and A14 to match the positron beam into the downstream focusing system that consists of only triplets, as shown in Fig.6. With this focusing lattice then the positron beam envelopes are less than the bore radius of the accelerating tube due to the strong focusing offered by the larger aperture quads[3].

The polarities of the triplets are rearranged to be DFD-FDF for both electron and positron beams. When the linac operation mode is switched from positron to electron, one just switches off all big quads and resets the triplet's gradients, keeping their polarities constant for the ease in operation, as shown in Fig.6.

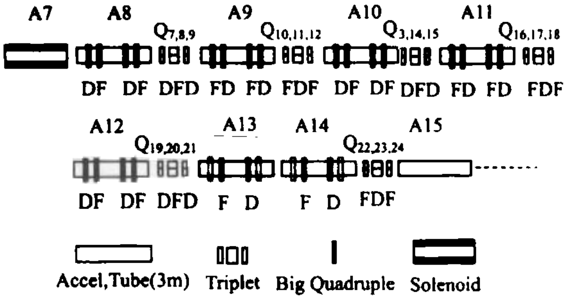

Fig.6.　Focusing lattice for the positron beam.

2.5 Optics correction

An on-line optics correction loop has been preliminarily designed according to the lattices given above[3]. The output rf power from each klystron (given by the measured voltage of each modulator and the prepared curves of klystron output vs. modulator voltage) is one of the input data for the correction loop to define the beam energy at each quad. The fitted gradient values of each quad and their corresponding power supply's currents will be one of the output data of the loop to control/reset the quad's power supply.

2.6 Emittance measurement

To know the real beam emittances for making a well matching of the beam from the pre-injector to the main linac and from the linac exit to the transport line, the emittance measurement devices have been installed at the pre-injector exit and improved at linac exit in the summer 2001. These devices are optimized for having the precise and reproducible measurement results[5].

3 Orbit correction

3.1 Correction scheme

In the BEPC Ⅱ-Linac upgrade, a beam orbit correction loop will be established to partially cure the initial beam offset effects and the machine alignment error effects on the beam emittance growth and orbit deviation. An "1-to-1" orbit correction scheme is adopted. A stripe-line BPM is located in the upstream gap of each triplet, and a set of correctors (both for x and y directions) is "ridded" on the upstream accelerating structure, as shown in Fig. 7. The prototypes of a BPM and a pair of correctors (for x and y) have been made with good measured results[6,7].

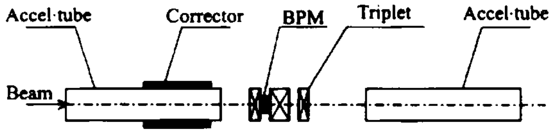

Fig.7. Locations of correctors and BPMs.

3.2 Modeling of electron beam orbit correction

In the modeling, the initial beam offset, quads offset and accelerating structure offset have been taken into account with LIAR-code[8]. The maximum electron bunch charge is 2.33 nC with its assumed energy spread of 2.5 MeV at the pre-injector exit (30 MeV). Above errors induced chromatic/dispersive effects in the quads, the short-range and long-range wake effect in the structure have been calculated separately first[3], and then combined, with and without orbit correction. To have a minimum energy spread at the linac exit, the optimized accelerating phase of -3.5° is chosen to compensate the single-bunch beam loading effect[3]. Fig. 8 shows the orbit correction effect on partially curing the beam emittance growth vs. initial beam jitters and machine errors.

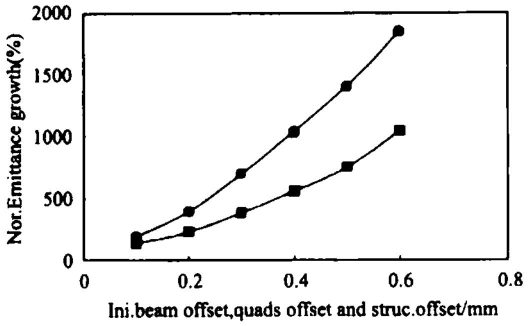

Fig.8. Emittance growth vs errors.

Upper without orbit correction; lower with orbit correction.

3.3 Modeling of positron beam orbit correction

Similar to the electron beam orbit correction, Fig.9 shows the correction effects for the positron beam. In the case of positron beam, the large energy spread ($\Delta E = 12$ MeV) induced chromatic/dispersive effects is dominated, while the wake effect for bunch charge of only 21 pC is negligible.

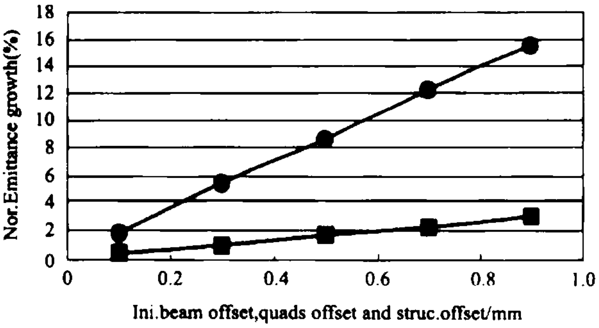

Fig.9. Emittance growth vs errors.

Upper without orbit correction; lower with orbit correction.

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BEPCⅡ-Linac束流光学和轨道校正的优化研究

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摘要　为实现BEPCⅡ的总体要求，对直线注入器的强流电子束和正电子束进行了系统的束流光学模拟和优化研究．提出了束流光学的自动校正环路．系统地研究了束流初始偏轴和加速器部件的安装误差对束流归一化发射度和轨道偏移的影响．提出了采用“一对一”的束流轨道校正机制，以有效抑制这些影响，确保直线注入器的束流性能．

关键词　电子直线　束流光学　轨道校正

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